Seismometers and the Insulation Box

Gregory E. Vansuch, University of Colorado at Boulder
Jan Harms, Ph.D., California Institute of Technology
LIGO SURF Progress Report 1
July 1, 2010

Abstract

Newtonian noise study at the former Homestake mine in Lead, South Dakota requires computers for reading out data. When placed in the Homestake environment and not shielded from factors such as humidity the computers will malfunction. For minimizing effects from factors like this the computers will be placed in a box. The design of such a box is not easy to come up with, and this summer an option for one such box was designed, tested, and decided with small modifications it would be the correct type of box to use. Also, the Trillium T-240 seismometer is in the process of being mimicked and modified in attempt to create a seismometer that will read seismic noise at higher frequencies near 10 Hz.

I. Introduction

Due to a sudden accident at the former Homestake mine in Lead, South Dakota, research plans (refer to source 5) were altered from research/modification in the mine to research for the mine at Caltech. Each seismic station at Homestake contains a computer to read data, and this computer is located in a box. Computers function best in optimum environments where humidity is low and the temperature is around 20-30 degrees Celsius. In the mine these types of conditions are hard to meet, and only 2 of the 8 computers at Homestake are currently functioning due to humidity, as there was no attempt to shield these from it. It was thus necessary to shield the computer from the humidity, and it was decided the best way to go about this was placing the computer in a thermal insulation box. It was also decided that while using the box the temperature around the computer should attempt to be lowered significantly for even better conditions than just lower humidity (the temperature was already fine at 30 degrees Celsius, but a cooler temperature in the range of 20-30 degrees Celsius would be more optimum).

The first box contained a fan running inside and outside of it. The computer survived humid conditions and the temperature inside was brought down to around 30 degrees Celsius, fair enough for the computer, but improvement in temperature was still sought. An idea was proposed to build a cooling system inside the box allowing air to circulate better. So far the computer had been sitting on the bottom of the box with a fan running to cool it off. A fan was placed outside to cool the outside of the box, in hope to keep in the inside cool as well. This was working, with the box at 30 degrees Celsius, but the hope for yet a still cooler box was there. The computer needed to be lifted up somewhat from the bottom of the box to let the air flow better.

The idea evolved into creating a circulation system where air paths were created for air to flow on the bottom and top of the box. Along with this, the sides of the box would be black. With the sides black, thermal insulation would occur. Heat from inside the box would flow straight through the sides to the outside the box. Construction took place during the week of June 7th to the week of June 21st. The process and results are described in Section II. The overall result was little changed with the circulation system added to the modification that had brought the temperature to 33 degrees Celsius.

Along with this the beginning of a plan of for mimicking the T-240 seismometer and making modifications to improve its sensitivity at around 10 Hz has been developed. The goals were outlined and a PCB board for the amplification system designed on ExpressPCB. Noise curves limiting the T-240 must be modeled and ways to modify seismometers to improve the sensitivity at lower frequencies carried out. The full plan for this modification of seismometers is given in more detail in Section III.

II. The Box

The first task of the summer was building the box that contained the proposed cooling system to let a computer survive in it while at Homestake. The ultimate goal was to bring the temperature inside the box down a decent amount from an early design that brought the computer's temperature to 30 degrees Celsius.

Materials:

12x24 inch .036in aluminum, black (4)
24x24 inch .036in aluminum, black (2)
2.5x23 inch .0655in aluminum (20)
Bend into L's so that the 2.5 inch is bent into 1.5 and .75inch segments
1x22inch .13in aluminum (4)
Bend into L's so the 1inch is bent into two .5inch segments
1x10inh .13in aluminum (8)
Bend into L's so the 1inch is bent into two .5inch segments
Ruler (standard 12 inches)
Drill that can hold a drill bit to drill the size hole the rivets fit
2 clamps
Permanent marker
Aluminum Water Proof Tape

From McMaster-Carr:

Loctite Hysol Adhesive Cartridge, E-60NC Electrical Potting Epoxy, 1.69 oz (50ml), 6430A27. Quantity: 6
Dispensing Gun for 1:1, 2:1 50mL Cartridge, 74695A71. Quantity: 2
Bayonet Mixer Nozzle, 5.9'' L with 1/4'' Taper Tip, 74695A12
Did not come with the order and was not used, but is needed for building the box properly
Pop Blind Rivets: Poppack 100
AD44BSLF203
Aluminum
Recommended grip range : .188-.250in
Recommended hole size: .129-.133in
Rivet: aluminum
Mandrel: coated steel
Lot no. 409417
97517A320. Quantity: 4
Comfort Grip Blind Rivet Tool with 4 Nosepieces (3/32'', 1/8'', 5/32'', 3/16''), 6862A21. Quantity: 1

Building the Box

The dimensions of the box were to be 12’’x24’’x24’’. To begin building it, two 24’’x24’’ and four 12’’x24’’ black aluminum (.036in) pieces were ordered. When these arrived the 12’’x24’’ were placed on a table where the 24’’ were on the horizontal and the 12’’ on the vertical. Using a ruler .5’’ was measured from each corner horizontally and this .5’’ line from the horizontal drawn up vertically for future reference (measure in on the x axis .5’’ and then draw where the .5’’ mark is, aka x=.5 in a graphical sense). Following a mark every 2’’ on the vertical was made up through the 10’’ mark and drawn across horizontally (lines y=2,4,6,8,10 in a graphical sense). Both of these steps were applied to both sides of the two 12’’x24’’ pieces.

Figure 1: The holes were marked on both the L's and the black aluminum so when more drilling and riveting occurred the holes would be in the right places.

These lines would help place the cooling system which would consist of twenty 2.5’’x23’’ aluminum pieces bent into L’s with segments of .75’’ and 1.5’’ (It should be noted these L’s were bent by hand with a machine. It was attempted to have all the segments at .75’’ and 1.5’’, though none came out perfect). When laid down on the black aluminum pieces the L’s were placed where the .75’’ segment was on the aluminum and the 1.5’’ segment was in the air.

The next step was to take 10 of the .13 aluminum pieces (5 for each side of both 12’’x24’’ black aluminum pieces) and to measure 40cm inward on each end of the pieces along the x axis and 10 cm from the bottom (part that faces away from the bend) on the x axis and make the mark of an X where the 40cm and 10cm point met (intersection of y=40 and x=10 in a graphical sense). There will thus be 2 X marks on each of these 10 pieces. This is where drill holes were to be put. To drill these L’s a drill piece was found that would fit the rivets eventually used to rivet one L, the black aluminum, and an L below that, together. The size of the hole these rivets make are .129 .133 inches. The drill bit used with this box was in fact a bit bigger due to supply limitations (the bits within the proper range were too dull to use). A hole was then drilled through at each X mark and labeled, which would be handy later (see Figure 1).

The following was then done.

With a clamp, one of the L pieces previously drilled through was lined up on the black aluminum board at the 2’’ mark and .5’’ from the edge of the board as horizontally as possible. This was done by using a ruler to draw a straight, horizontal line across the board at y=2 (and was done for the other points as well). Then, with a clamp, one of the L’s with no holes drilled through it was lined up on the other side of the piece at the 2’’ mark and lined up with the other L as well as possible and then clamped to it. Each L was made sure to be as straight as possible by making small adjustments with removing the clamp and realigning as needed.

Then the drill was placed in one of the holes that had been drilled earlier on and the black aluminum and other L were then drilled through. The resulting holes were labeled (for example, if three holes were in the same set, (a hole in one L faced a hole through the black aluminum which faced a hole in the other L below it, one could mark these holes as 1A top, 1A, 1A bottom). This process was done for all the 2'' marks on both 12''x24'' pieces.

When this drilling was complete it was time for gluing and riveting the L's onto the black aluminum. To do this sets of L's (one on one face of the aluminum, one on the other) were glued down, and right after riveted together.

Problems that occurred in this step are noted here. At first only the L's for the top black aluminum piece were glued out of misunderstanding of directions. It was decided, due to this misunderstanding, to wait until the next day to glue the bottom pieces, and once all the glue was dried the pieces would be riveted together. It was fortunate this mistake was caught right away. If waiting to glue the bottom and then doing the riveting had taken place, the box would not have turned out so well, as the pieces would have shifted while drying so the holes would have not been in place, so riveting would have been very, very difficult.

Also, the glue being used needed a mixer to work properly, and no mixer was sent. This was not realized until much gluing had taken place, so the glue had to be mixed by hand, the result quite a mess as seen in Figure 2. Proper gluing would have required this mixer for the glue gun.

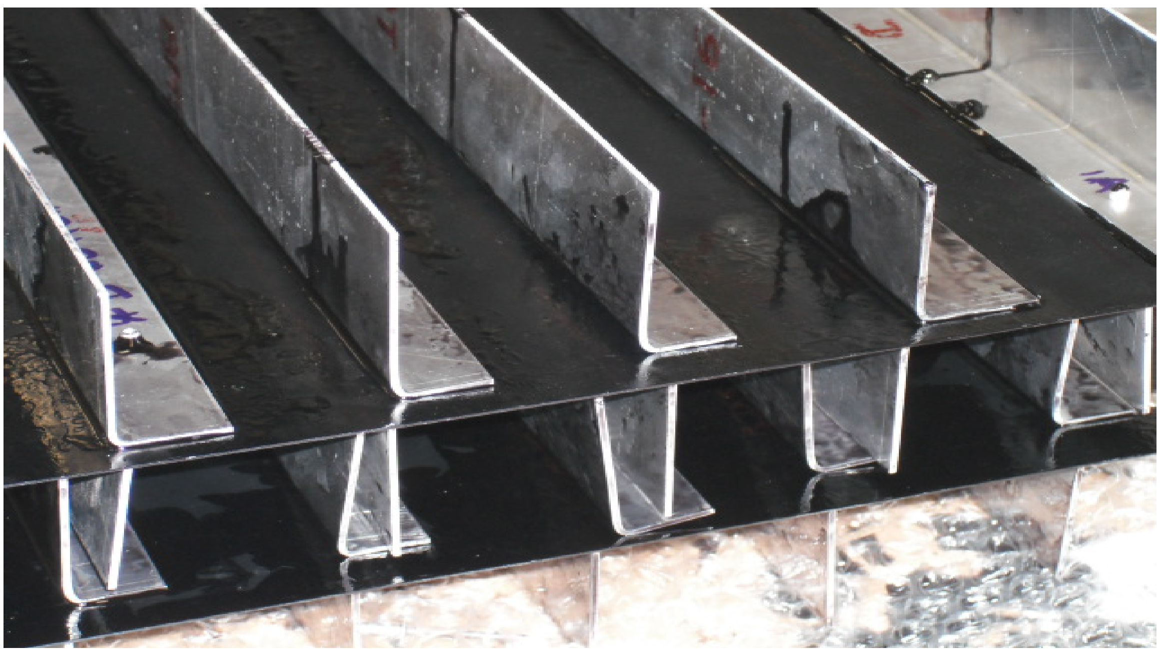


Figure 2: The result looked like this. It did not matter which direction the L's were glued, but here, except for one mess up, the top of the black pieces had the L's facing to the right, the bottom L's facing to the left.

When the glue had dried, which was much later than expected (it should have been 24 hours, but this was about five days later, and the glue was still a bit wet) it was time to make the box. On each piece of the box it was decided which side would face outward and inward (the outward parts would contain the smooth side of the rivet to place tape with more ease around the edges of the box as soon described). A 1'' mark from each edge on the inward portion of the box pieces was made. These would be where the four 1''x22'' and eight 1''x10'' .13in aluminum pieces, bent into segments of .5'', would be placed. Each of the black aluminum pieces were to contain two of the L's on its side, riveted to it and its partner black aluminum piece as the box was put together (see Figure 3). The .13in aluminum pieces were lined up at the 1'' marks in each corner and positioned in a way such that it lined up with the edge of the black aluminum perfectly. Clamps were used to keep these in place, and 3 holes were drilled through each of the 1’’x10’’ pieces, 4 holes for the 1’’x22’’ pieces. The top piece of the box was not riveted to the rest of the box since the top needs to be removed easily to put in and take out items from the box. To seal off gaps aluminum water proof tape was put around the edges and holes in the box (each of black pieces had 4 holes near the corners. This was not intentional; the manufacturers delivered the pieces this way).

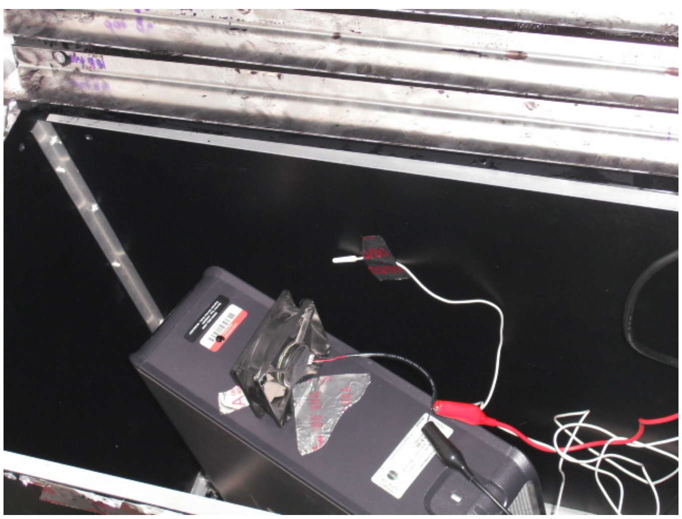
Figure 3: How to rivet and position the .13 aluminum.

The box was now equipped with scientific instruments. The computer was placed on the cooling system at the bottom of the box. This computer was then connected to a monitor located outside the box. A small fan was taped on top of the computer with its wire attached to the black end of a BNC connector. A temperature sensor was attached to the side of the box and its wire connected to the end of a red BNC connector. This way the fan could be turned on and off and the temperature read out with the box closed as the other end of the black BNC was connected to the switch that turns the fan off and on and the readout screen of the temperature sensor sat on a table outside the box. For better visualization inside the box see Figure 4.

With everything inside and the computer running the top of the box was put in its place. It would not go down all the way as there were wires connecting devices in the box to outside the box. To seal it as best as possible the aluminum tape was used in the same way as on the other sides. It was now time to determine if this box improved the inside the box as compared to the modification from before.

Ideal results placed the aim for temperature significantly under 30 degrees Celsius. At 10:00 am the measurements began. At first the inside fan was turned on, then the outside. The temperature started out in the 40’s and by 11:30, when it was a reasonable time to see what temperature the cooling system would allow the box to be, it was 28.7 degrees Celsius. The goal for under 30 degrees was attained, but only by an absolute value of 1.3, not enough to make a difference.

Figure 4: The box with the computer, fan, and heat and temperature sensor inside.



A good portion of the box design/cooling system will remain. The box design itself will not change, as the .13in aluminum L’s and tape were found to make the box much more sturdy and the black .036in aluminum will keep heat absorbed within the walls and not flowing around in the box as much. Since the cooling system did not make much of an improvement, only the 10 L’s making up the bottom portion of the box’s cooling system will remain. The idea behind this is the computer will not sit directly on the bottom of the box allowing for air to move more freely and the box itself not touching the ground directly allowing for air to move under. Both of these key points could keep heat from building up under the computer/box and avoid unnecessary temperature increase.

Small modifications will also be made to the 10 cooling system L's as well. When glued onto the black aluminum pieces, some were closer than .5'' to the edge of the black pieces resulting in modifications to the .13in aluminum L's (the pieces that were riveted at the sides of the box in Figure 3) being necessary to fit them next to the cooling system along the 12'' axis. It was decided where the .13in pieces needed to be shorter to fit onto the black pieces just right and then a filer was used to cut the pieces accordingly. To avoid this in the future the cooling system will have L's that are 2.5''x21'' bent into .5'' and 1.5'' segments.

Seven to eight more boxes will be made in the near future for use at Homestake.

Section III. The Seismometer Project

The current generation of LIGO has a noise curve which shows the strain equivalent instrumental noise spectrum [1]. Advanced LIGO is designed with increased sensitivity, especially at low frequencies (see Figure 6). One of these noises to be read at lower frequencies is Newtonian noise.

Seismic fields create perturbations in the ground causing the ground to displace ever so slightly on the vertical and horizontal axis [1]. This creates a change in density around a test mass which changes the gravitational field, the result being a force displacing this test mass along the horizontal axis a very small magnitude. This displacement is NN [1]. Since this noise is a direct result of seismic noise, the better the understanding there is of seismic noise, the better the understanding of NN [1].

The former Homestake mine in Lead, South Dakota is an ideal location for studying NN. Reaching depths of 4100 ft for scientific study, the mine contains less seismic noise, and thus NN, than above ground [3]. Using a test mass system, a seismometer takes the distance a test mass is displaced in result of seismic fields and converts this into an electrical signal [1]. This signal is put through a readout system where it undergoes some amplification before being recorded [1]. Using the electrical signal result and the simple result of how much the test mast was displaced, NN is then modeled [1].

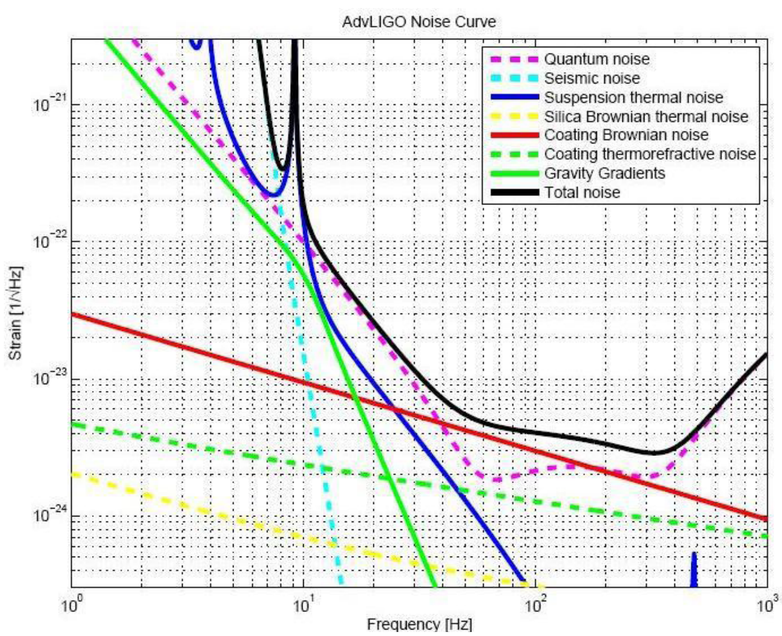


Figure 5: Goal for Advanced LIGO noise curve. In the old curve each noise strain would be located at a higher frequency.

Currently, there are 8 seismometers at Homestake in a 2D array which will soon be reconstructed into a 3D array [2] with the goal of figuring out origins of NN, of which little is known [1]. These origins would be where the seismic fields' induced gravity perturbation begins to affect a test mass noticeably. An understanding of how the density and gravitational field around a test mass change would then be possible, and with this predictions of how the test mass will shift with change in the gravitational field will develop [1]. If NN could then be understood at all frequencies these predictions would permit subtraction of the noise from GW measurements [1]. This is necessary because, unlike in Figure 6, which is a bit optimistic about the placement of the NN curve, it is predicted NN will limit future generations of LIGO [1]. Future generations of gravitational wave detectors will use frequencies around 10Hz, and it is necessary to understand NN at this frequency as it will mix with the data at this frequency, and with no way to subtract it out the data will be difficult to analyze [1]. The seismometers used at Homestake, however, are designed for frequencies well below 10Hz and must be modified [1]. Only then will seismic fields, and in result NN, be understood at 10Hz [1].

Modifying a seismometer is in early stages. The main idea is to improve seismometer sensing at higher frequencies (10-30Hz) for seismic noise study [1]. The plan to achieve this is building a seismometer modeled off the Trillium T-240 [1] to sense the small displacements at higher frequencies and thus converting these into an electrical signal at lower frequencies and a new readout system with less noise in its amplifiers [1].

The readout system was designed on ExpressPCB (see Figure 6). There are four capacitors on it. Each is in series with one of the other capacitors and in parallel with the other two [1]. On the top portion of the board one of the sets of capacitors in series are connected to the ground at one end of each of the capacitors, and the other set is connected to the input signal the same way. On the bottom of the PCB board the other ends of the capacitors are connected to the readout system where an amplifier will be located. The input/ground and the output are both made of two BNC connectors. A low noise pre-amplifier will be used to limit electronic noise in the system [1]. This readout system will then amplify the electrical signal given by the seismometer.

The seismometer that will be built is hoped to have sensitivity of seismic noise at 10-30 Hertz [1]. What limits the T-240 from this are mechanical factors: creeps in electrodes, vibration, thermal expansion, atmospheric pressure and humidity change, basic distortion, and weight force changing direction when the transducer is tilted and electronic factors such as amplifier noise [1], [4].

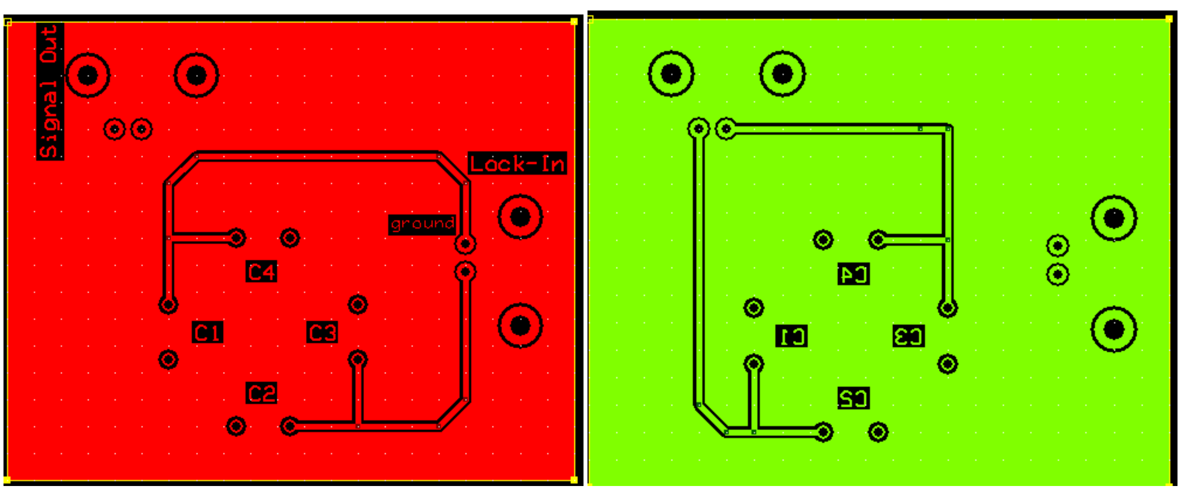


Figure 6: Figure 6: Top (red) of the PCB board and bottom (yellow-green) of the PCB board.

To counter these limitations, noise curves of the T-240 will be modeled [1]. With the models it will be determined which type of limitations are best to focus on when designing the seismometer. The mechanical and electronic design of the seismometer will then be modified on paper to make sure all the small points in the modified design are considered [4], and then carried out in construction.

Sources:

[1] Hans, Jan. notes from personal conversations. June 9-July1, 2010.

[2] Harms, Jan, et al. Characterization of the seismic environment at the Sanford Underground Laboratory, South Dakota. *LIGO Document*, DRAFT, 2010.

[3] Harms, J., Sajeva, A., Trancynger, T., DeSalvo, R., Mandic, V. Seismic studies at the Homestake mine in Lead, South Dakota. *LIGO document*, page T0900112-v1-H, 2010.

[4] Jones, R.V. and Richards, J.S.C. The Design and some applications of sensitive capacitance micrometers. *J. Phys. E: Sci Instrum*, 1973.

[5] Vansuch, Gregory E. Subtraction of Newtonian Noise. 2010.